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Second language acquisition across modalities: Production variability in adult L2 learners of American Sign Language

Allison I Hilger
Purdue University, USA

Torrey MJ Loucks
University of Illinois at Urbana-Champaign, USA

David Quinto-Pozos
University of Texas at Austin, USA

Matthew WG Dye
University of Illinois at Urbana-Champaign, USA

Abstract

A study was conducted to examine production variability in American Sign Language (ASL) in order to gain insight into the development of motor control in a language produced in another modality. Production variability was characterized through the spatiotemporal index (STI), which represents production stability in whole utterances and is a function of variability in effector displacement waveforms (Smith et al., 1995). Motion capture apparatus was used to acquire wrist displacement data across a set of eight target signs embedded in carrier phrases. The STI values of Deaf signers and hearing learners at three different ASL experience levels were compared to determine whether production stability varied as a function of time spent acquiring ASL. We hypothesized that lower production stability as indexed by the STI would be evident for beginning ASL learners, indicating greater production variability, with variability decreasing as ASL language experience increased. As predicted, Deaf signers showed significantly lower STI values than the hearing learners, suggesting that stability of production is indeed characteristic of increased ASL

Corresponding author:
Matthew WG Dye, Department of Speech and Hearing Science, University of Illinois at Urbana-Champaign, 901 S 6th St, Champaign, IL 61820, USA.
Email: mdye@illinois.edu

use. The linear trend across experience levels of hearing learners was not statistically significant in all spatial dimensions, indicating that improvement in production stability across relatively short time scales was weak. This novel approach to characterizing production stability in ASL utterances has relevance for the identification of sign production disorders and for assessing L2 acquisition of sign languages.

Keywords
American Sign Language, L2, motion capture, production, spatiotemporal index

I Introduction

1 Overview

Sign languages are the natural languages of Deaf[1] communities and possess phonological systems, morphological systems and syntactic rules, operating within complex grammatical systems (Sandler and Lillo-Martin, 2006). The acquisition of sign languages by Deaf children with Deaf parents follows the general milestones that characterize acquisition of spoken language for hearing children (Petitto and Marentette, 1991). Sign languages also exhibit sociolinguistic variation (Lucas, 2001) and undergo historical change (Frishberg, 1975). They differ from spoken languages primarily in that they are expressed in the visual–gestural modality, rather than the oral–aural modality.

Second language acquisition of sign languages by individuals who have a spoken language as a first language (L1) is of particular interest. This is because it not only requires learning lexical items and a grammatical system, but the language must be produced with an entirely new articulatory system. Acquiring a new articulatory system in a second language (L2), involving the use of the hands, arms, and facial expression, is a novel challenge for learners who have a spoken language as an L1. Importantly, these effectors also present a research advantage in that the articulators are all visible, in contrast to speech articulators such as the tongue that are often hidden from view and difficult to observe. The focus here is on production stability in hearing L2 learners of American Sign Language (ASL), and in particular their ability to consistently reproduce utterances. We define high production stability as the ability to reproduce lexical targets from a sign language with low spatiotemporal variability in the movement of the dominant articulators. Our motivation for focusing on path movement comes from descriptions of joint usage in hearing L2 learners of ASL (Mirus et al., 2001), movement errors in L2 signers (Rosen, 2004), and descriptions of dysfluencies in deaf signers (Whitebread, 2004, 2014). The production variability can be used as an index of the robustness of the motor representations acquired by the hearing L2 learner (Sadagopan and Smith, 2008).

Whilst there have been several studies of sign language acquisition as an L1 in deaf individuals (Newport and Meier, 1985; McIntire, 1977; Meier and Newport, 1990), comparatively little is known about L2 acquisition in hearing individuals. Mirus et al. (2001) looked at limb movements in adult hearing learners acquiring ASL as a second language, motivated by prior research showing that Deaf children learning sign language often proximalized movements that required more distal articulation, or used articulators closer to the torso when articulators further away are required (Meier et al., 1998). Hearing adults with little or no prior sign language knowledge were asked to imitate a set of signs from either ASL or German Sign Language (Deutsche Gebärdensprache or DGS). Additionally, native or near-native Deaf signers of ASL were asked to imitate a set of signs from DGS to determine whether familiarity with the manual modality played a role. Mirus et al. (2001) reported that proximalization of signs was frequently observed in the adult hearing learners but not in the Deaf ASL signers imitating signs from DGS, suggesting that the native signers have acquired motor skills that could be transferred to articulation of other sign languages. Other studies have described movement errors that are produced by L2 learners. One implication of these findings is that second language acquisition of a sign language for adult learners with no prior sign language experience may require additional learning steps compared to spoken L2 acquisition, i.e. a complex new set of motor skills is required.

One premise of this study was to develop a technique for quantifying production stability in sign language, useful for the examination of acquisition of sign language as well as in the study of production disorders, in which communication is inhibited by the inability to fluently produce language. To date, only anecdotal and survey-based research exists regarding the existence and prevalence of stuttering in signed languages (see Whitebread 2014 for a review). However, it is of particular interest due to its classical definition of stuttering as a *speech* disorder in which dysfluency perturbs the forward flow of speech (Bloodstein and Ratner, 2008): the occurrence of stuttering in sign language could redefine the disorder as a language disorder that is not specific to the speech-motor system (Snyder, 2009; Whitebread, 2014).

Research in this area has been scarce due to the difficulty of studying a smaller clinical population. The prevalence of deafness is 1.4% worldwide (Stevens et al., 2013). Within this population is a smaller community of individuals who identify as culturally Deaf and use American Sign Language. Identifying the 1% of people who stutter within the 1.4% of people who are deaf and use sign language adds difficulty to this research (Månsson, 2000). Many studies have used surveys to gather information about stuttering in the deaf population (Backus, 1938; Cosyns et al., 2009; Harms and Malone, 1939; Montgomery and Fitch, 1988; Silverman and Silverman, 1971). Overall, the prevalence of reported stuttering in sign language is approximately 0.12% (Montgomery and Fitch, 1988; for a comparison of various studies, see also Whitebread, 2014). Disparity across studies may be due to survey bias, poorly delineated definitions of stuttered sign, and lack of specificity that left interpretation up for bias. Whitebread (2004, 2014) developed a list of potential characteristics in an effort to clarify misinterpretations of stuttered sign, including: interjections in sign or fingerspelling, dysfluencies occurring at the beginning of a sign gesture, hesitation of sign movement, repetition of sign movement, exaggerated/prolonged signs, unusual body movements, lack of sign fluidity, and inappropriate muscular tension. Overall, we propose that a quantifiable tool for measuring stability in sign language production will help to better examine production disorders in sign language, such as stuttering, by allowing us to hone in on the specific movement deficits that may occur during production. The current study explored the production variability of L2 learners of ASL as a first step in understanding the variability that exists in sign language production in typical and atypical populations.

2 Characterizing production variability

The study reported here is an initial attempt to explore production variability in hearing adults learning American Sign Language (ASL) as an L2 on a university campus in the USA. Kinematic analyses have been employed by speech scientists to observe stability and sequencing of the speech articulators such as the lower lip and jaw (Smith et al., 1995), and has the potential to be useful when applied to production stability in sign languages. This study uses the spatiotemporal index (STI); this is a measure, based upon kinematic data, which has been used to examine production stability in speakers of varying ages and communication disorders, under differing speaking conditions such as rates of speech, complexity of utterances, and so forth (Kleinow and Smith, 2000; Maner et al., 2000; Smith et al., 1995; Smith and Goffman, 1998; Smith and Kleinow, 2000). The STI measures kinematic, or movement, variability in utterances over repeated performances in order to determine an individual's production consistency (Smith et al., 1995). It is measured by producing a target phrase for a specified number of repetitions (often randomized within a larger set of phrases) while lip and jaw movements are recorded under a motion capture system, and the resulting displacement waveforms are amplitude- and time-normalized for comparison. The standard deviations are then computed at 2% intervals for a total of 50 values that are summed to provide the resulting value of movement variability, or the STI, for that target utterance (Smith et al., 1995). This method of movement analysis provides a quantifiable and consistent tool to measure movement stability, applicable to a diverse set of research questions. The underlying premise for this measurement tool stems from the idea that movements, particularly in speech, are highly coordinated and automatic such that repeated productions demonstrate a high degree of consistency and stability in a person with no history of motor or language impairment. In contrast, greater variability then indicates an aberration in motor control, either due to development of the motor system, exemplified in young children, or abnormalities in the neural speech motor network, as seen in people who stutter (MacPherson and Smith, 2013).

Originally, the STI was employed to examine underlying production components in speech, looking at the preprogramming of speech movements by observing the stability of repeated productions of an utterance by a normal adult speaker in the absence of perturbation (Smith et al., 1995). The analyses found that the typical adult produces an average STI of 13.3 with a standard deviation of 2.5 ($n = 54$) (Kleinow and Smith, 2000; Maner et al., 2000; Smith et al., 1995; Smith and Goffman, 1998). Production stability in the normally-fluent adult can be affected by aberrant speaking conditions, for example, when the rate of speech is slowed down, resulting in an increased STI range of 13.5 to 22.9 (Smith et al., 1995). The STI has also been measured in children, finding that the speech movement variability is significantly greater when compared to adults, demonstrating an average STI for four-year-olds of 24.1 (SD 4.0) and an average of 18.5 (SD 5.7) in seven-year-olds (Maner et al., 2000; Smith and Goffman, 1998). The STI has been used to examine movement stability of oral articulators in stuttering as well (Kleinow and Smith, 2000; Smith and Kleinow, 2000). Adults who stutter exhibit significantly greater speech movement variability than normally-fluent adults, particularly when producing utterances of increasing length and complexity (Kleinow and Smith, 2000). These average values range from approximately 10.3 to 23.8 in adults who stutter (Kleinow and Smith, 2000).

Additionally, children who stutter exhibit greater speech motor variability than their typically developing peers (MacPherson and Smith, 2013). Overall, fluent speakers show speech movements that are highly automatic and stable, whereas a person exhibiting dysfluencies, such a person who stutters or a young child, shows less stability / higher variability (Kleinow and Smith, 2000; Smith and Goffman, 1998).

Chakraborty et al. (2008) used the STI to study second language acquisition in Bengali learners of English. They reported no significant differences between the STI values for the speakers' L2 and L1, suggesting that production stability (as indexed by the STI) may not be a fluency characteristic in adult second language acquisition of spoken languages. This suggests that there is significant transfer of articulatory control between two languages that share a common set of articulators. Due to the need to learn new motor plans to control the effectors required to produce a sign language, we hypothesized that L2 sign language acquisition would result in higher levels of production variability as indexed by the STI. We also predicted that with increasing exposure to and practice in producing the language, movement instability should decrease until it approximates the levels observed in native or near-native Deaf L1 signers.

In order to do this, we calculated STI values for eight ASL sign productions embedded within carrier phrases produced by hearing L2 learners of ASL and proficient Deaf signers for whom ASL was an L1. We predicted that the Deaf proficient signers would show significantly smaller STI values (indicating less variability and stronger stability) than the hearing learners, reflecting the need to acquire a complex set of new motor skills in this population. We also predicted that STI values would be lower in hearing learners with more sign language experience, reflecting increasing automaticity of motor planning as a result of practice in producing ASL utterances.

II Methods

1 Participants

Participants were recruited from each of three levels of the ASL curriculum at the University of Illinois at Urbana-Champaign, and from the Deaf community in Champaign-Urbana, Illinois, USA. The ASL curriculum consists of ASL I (beginning level), ASL II (intermediate level), and ASL III (advanced level). Each level consists of 4 hours of classroom contact time per week with a Deaf instructor across a 16-week semester, in addition to weekly assignments. At the time of the study, students in ASL I had 8–14 weeks of classroom experience, students in ASL II had 22–28 weeks, and students in ASL III had 36–42 weeks. Four students were recruited from each level, in addition to four native, or near native, Deaf signers from the local community (Deaf, proficient signers). Thirteen of the participants were female and three were male (2 Deaf native signers, 1 hearing ASL I learner), ranging from 19 to 60 years of age.

2 Apparatus

Kinematic data was collected at 100 frames per second using 4 Hawk motion capture cameras (Motion Analysis Corporation, Santa Rosa, CA). The cameras emit and sample infrared light that is reflected from passive reflective markers placed on the participant. For each participant, markers were placed on the right shoulder, upper arm, upper elbow, lower elbow, wrist, and hand. A single marker to follow head movement was also attached to a pair of plastic glasses worn by the participant. Markers were calibrated for motions of less than 0.5mm using the procedures recommended by the Motion Analysis Corporation. Real-time video at 60 frames per second, time-aligned with the motion capture system, was also acquired.

3 Materials and procedure

Participants were seated 4–5 feet from a computer screen. Instructions were presented with a captioned video in ASL (Deaf L1 signers) or verbal instructions in spoken English (hearing L2 learners). Each trial consisted of a phrase appearing on the computer screen in English glosses of ASL signs, with a video demonstrating only the target sign. This allowed for the experiment to be accessible to the beginning signers while avoiding passive imitation. After each phrase, a slide showing the word 'STOP' appeared.

The stimuli consisted of eight target signs embedded in two carrier phrases (adapted from Emmorey et al., 2009). In order to maintain grammatical consistency, the target signs GROW-UP, STRAIGHT, DANCE, WIFE, and FURNITURE were embedded in the phrase THINK _________ YESTERDAY, while the signs PREACH, PUT, and LOOK were embedded in KNOW _________ YESTERDAY (see Figure 1). The participants were instructed to sign the phrase shown on the screen in a natural, conversational manner, and to begin and end with their hand placed on their right thigh.

For each sign, the participants were seated with the right side of their body facing the cameras so that forward–backward motion occurred in the Y-dimension, side-to-side motion in the X-dimension, and up–down motion in the Z-dimension. The stimuli were ordered randomly, with 10 trials for each of the eight target signs (eighty trials per participant).

4 Movement analysis

The right-hand marker was chosen for all analyses as it was clearly displaced across a large range of motion on each trial.

The target signs were extracted from the carrier phrase of the right-hand marker record using a custom Matlab script. The start and end points of the target sign were defined as the first and last valleys in the trace where the hand moves toward the body for the signs in the carrier phrase. This allowed for consistency across all signs for all participants.

5 Dependent variables

The STI was determined for the hand marker in all dimensions for each participant in order to quantify and compare movement variability across the 10 trials of each sign.

Figure 1. Illustrations of the eight target signs and two carrier phrases.

The STI is calculated by normalizing the displacement (Z-score) and temporal record of each movement trace following procedures established by Smith et al. (1995). After temporal normalization of all trials for a given sign to produce 1,000 time points, the standard deviation across the 10 displacement normalized trials was sampled at 2% intervals. The standard deviation (SD) indicates the temporal and spatial variability at a single point. By summing the SD values for each sign, an index of variability was derived that allowed an estimate of variability across the trials. Lower STI scores thus indicate more consistent or less variable movements. For each participant, an STI value was calculated for each sign. Averages of the STI values were then compared between the groups. In order to assess whether increased variability was driven by increased duration of utterance, the production duration of each sign in real-time based on the marker points was also recorded for each trial.

III Results

Linear mixed models were used to analyse the data using the MIXED procedure in SPSS (Windows version 21, IBM). The criterion for significance (alpha) was set at .05, and a priori contrasts were performed to test the experimental hypotheses.

The STI values were computed for each participant for each of eight signs, based upon 10 independent productions of each sign (a total of 80 tokens). In addition, the time it took participants to produce each token was recorded.

Linear mixed models were constructed with participant group as a fixed-effect (Deaf proficient signer, ASL III, ASL II, ASL I) and sign as a random-effect (GROW-UP, STRAIGHT, WIFE, DANCE, FURNITURE, LOOK, PREACH, and PUT). The models also included a participant group by sign interaction term, as well as sign production duration as a covariate. Three models were constructed to determine the contribution of participant group to variability in STI values in the X-, Y- and Z-dimensions. These analyses revealed statistically significant effects of participant group in all three dimensions (x: F (3, 123) = 8.04, $p < .001$; y: F (3, 123) = 6.40, $p < .001$; z: F (3, 123) = 3.80, $p = .012$), with production duration not a significant covariate in any analysis (all $F < 1$).

Next, we examined specifically whether the productions of hearing learners differed from those of the Deaf proficient signers. Taking production duration into account as a covariate, this showed a significant difference between the STI values of the hearing and Deaf signers in all three dimensions (x: F (1, 125) = 13.61, $p < .001$; y: F (1, 125) = 16.41, $p < .001$; z: F (1, 125) = 6.95, $p = .009$).

Finally, we analysed whether there was a significant linear trend in the STI values going from ASL I learners through to ASL III learners. Linear mixed models, with Deaf signers excluded, were statistically significant in the X-dimension (F (2, 92) = 4.39, $p = .015$), but not in the y (F (2, 92) = 1.03, $p = .361$) or z (F (2, 92) = 2.01, $p = .140$) dimensions.

IV Discussion

The kinematic variability of sign production in hearing learners of ASL was assessed using the spatiotemporal index (STI); this is a measure of production variability across repeated tokens of an utterance. Hearing learners at three proficiency levels were assessed and compared with Deaf proficient signers who acquired ASL as an L1 in infancy or early childhood. For hearing speakers acquiring a sign language for the first time, we predicted that production variability would be greater than for Deaf proficient signers because motor plans for speech cannot be co-opted for motoric production of sign (unlike for L2 spoken language acquisition; Chakraborty et al., 2008). As predicted, the STI values for hearing learners were larger than for Deaf proficient signers, reflecting greater variability in production across performance tokens in hearing learners. There was a small reduction in STI values across proficiency levels, at least in the x-dimension, suggesting that increasing experience of producing a sign language can result in more consistent articulation of the language as an L2. The most proficient hearing learners were still less consistent than the Deaf proficient signers. However, the most proficient learners in this study had only been using ASL for 36–42 weeks, compared to Deaf proficient

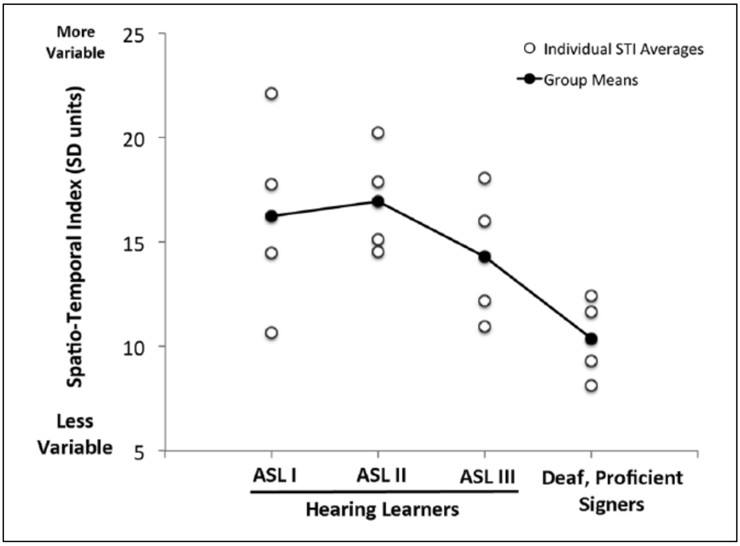

Figure 2. Spatiotemporal index (STI) values varied as a function of proficiency level.
Notes. Higher values indicate greater variability in production. Solid circles indicate group means, and open circles indicate STI values for individual participants averaged across signs. ASL = American Sign Language.

signers who had been using ASL as a primary language for 19–60 years. The STI values for the Deaf signers (M = 13.4, SD = 2.6) are comparable to typical adult speakers of an oral language (M = 13.3, SD = 2.5) (Kleinow and Smith, 2000; Maner et al., 2000; Smith et al., 1995; Smith and Goffman, 1998). In addition, the L2 learners (M = 18.1, SD = 4.2) showed comparable STI averages to seven-year-old children acquiring their L1 (M = 18.5, SD = 5.7) (Maner et al., 2000; Smith and Goffman, 1998), further supporting the immaturity of the motor system for sign language articulation in L2 hearing college students.

We interpret these results as reflecting subtle refinement of the motor plans needed to produce ASL signs in hearing L2 signers, with increasing experience leading to more stable representations of those motor plans and consequently less production variability. However, this does not necessarily entail increased linguistic fluency in the language itself. Indeed, post hoc inspection of some productions by hearing learners suggested that while they were consistent in how they articulated signs, their articulation patterns often diverged qualitatively from that of Deaf L1 signers. For example, participants produced the sign GROW-UP by placing a ‘B’ handshape palm-downwards in front of the signer, and then moving that handshape upwards twice to successively higher locations (see Figure 2). When the Deaf signers produced the sign, movement in the Y-dimension was smaller in the second than in the first movement, whereas the hearing learners produced successively larger movements (Figure 3). This may have reflected an initial ‘setting up’ of the sign (first movement) followed by the movement associated with the sign itself (second movement). Such differences may have been introduced as artifacts due to the use of citation forms of signs, or may reflect a looser more ‘sloppy’ signing style in the

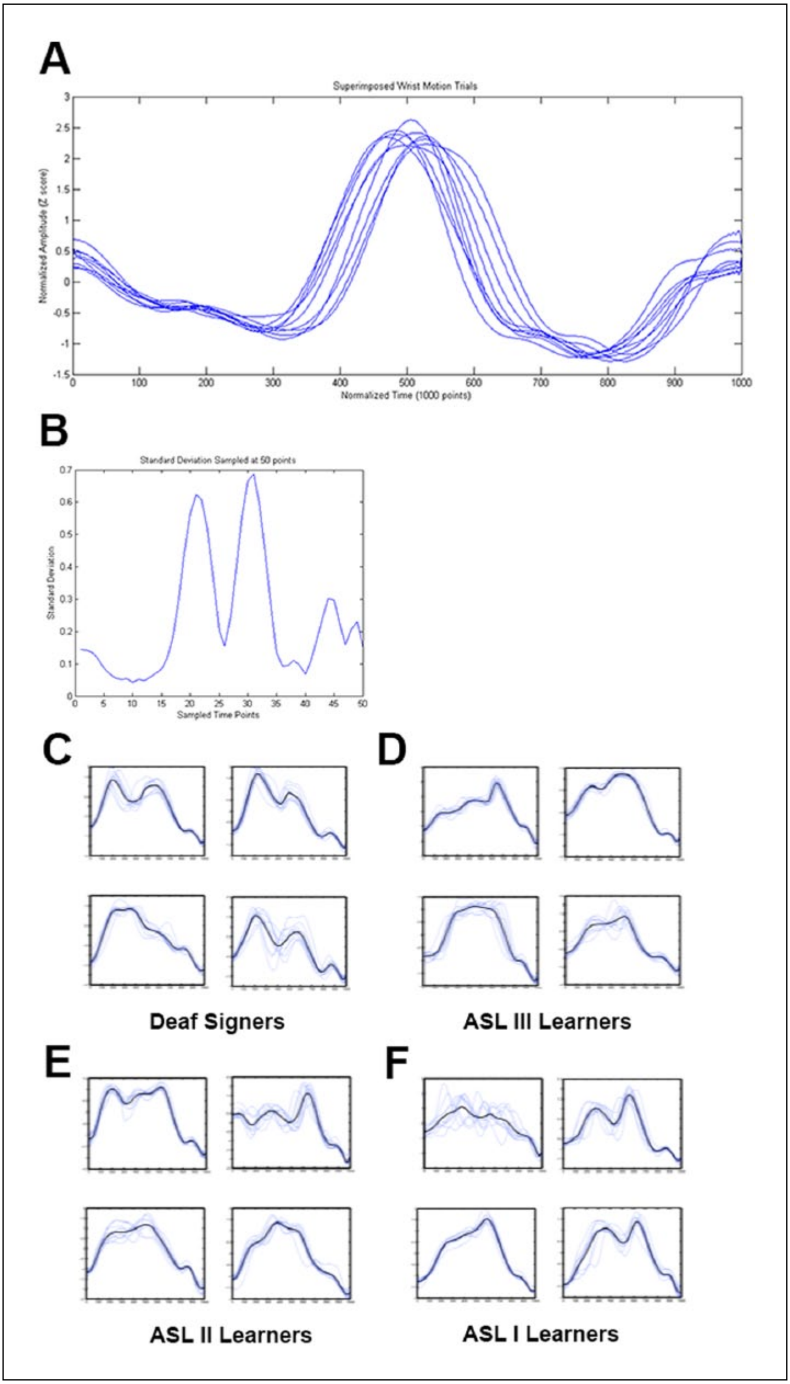

Figure 3. **A.** In order to compute the spatio-temporal index, wrist displacement in the Y dimension across several trials is initially normalized in time (plotted here on the *x*-axis such

Figure 3. (Continued)

that each trace has a duration of 1,000 time points) and space (plotted here on the *y*-axis as a z-score). **B.** Using the normalized data, the standard deviation of the displacement across trials is computed at 50 time points. The mean of the 50 standard deviations is the spatio-temporal index. **C–F.** Spatio-temporally normalized wrist displacements are shown here for each subject for the sign GROW-UP. The lighter traces represent the individual normalized displacements for each token of the sign, and the bolded line shows the average displacement around which the standard deviation was computed. Visual inspection of the traces reveals that most Deaf signers (**C**) and ASL III learners (**D**) demonstrate relatively little variation around the mean displacement compared to ASL II learners (**E**) and ASL I learners (**F**).

hearing L2 learners resulting from proximalization of movement (compare Mirus, et al., 2001).

It is also worth acknowledging the large variability in the STI indices within groups (Figure 2). One ASL I student and two ASL III students had STI values similar to those of Deaf native signers. So, at least for individual signs within short carrier phrases, some learners showed a remarkable degree of consistency. It is possible that some learners bring experience with them that may facilitate the acquisition of motor plans required for sign language production, or it may be the case that there are innate differences in the ability to acquire such motor plans. Being able to quickly instantiate stable motor plans that allow consistent sign production may provide such students with benefits in the sign language acquisition process. Stable production means that instructors may be able to spot linguistic errors more rapidly. It may also allow acquisition of the subtle production differences, such as those that constitute aspectual morphemes in ASL (Klima and Bellugi, 1979; Rathmann, 2005).

This study utilized a cross-sectional design that may have over-estimated the increases in production stability with experience for hearing L2 learners as a whole. At each level of the curriculum it is possible that some dysfluent L2 signers who are struggling with the language drop out of the ASL course sequence. While dropout rates are low, longitudinal studies with larger numbers of learners are needed in order to accurately generalize to the population of hearing L2 learners. This study focused only upon the movement of one arm. Fluent production of ASL requires the coordinated movement of the hands, arms and body, which must also be synchronized with movements of the head and facial features such as the mouth and eyebrows. Finally, these data come from the production of individual signs embedded within carrier phrases. Analysis of more complex utterances that require additional morphological and syntactic knowledge may reveal larger patterns of variability and more insight into how increasing grammatical competence is associated with production variability.

This research is not only critical to our understanding of stuttering and language, but also to clinical practice. Just like hearing children, deaf children who use a sign language are also at risk for communication disorders, and yet resources for therapists working with deaf children are lacking (Quinto-Pozos et al., 2011). Knowledge in this area is critical for improving clinical practice with such deaf children and other populations at high-risk for communication/language disorders. Future studies should compare the production variability of L2 learners with that of Deaf individuals whose production is atypical and may be characteristic of stuttering in the signed modality. It may also be beneficial for future work to use formal assessments of language competence rather than rely upon duration of language exposure measures. These may reveal stronger linkages between ASL competence and production variability measures such as the STI. Such knowledge has implications for teaching and assessment in both second language curricula and interpreter preparation programs, as well as for the diagnosis of communication disorders in Deaf children and adults. The sensitivity of the spatiotemporal index reported here suggests that it may be a useful pedagogical and clinical tool for sign language assessment as well as for spoken language assessment.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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Note

1. The use of the word ‘Deaf’ with initial capitalization is used to refer to individuals who socialize within communities of deaf people and use a signed language as a primary means of communication. The use of ‘deaf’ without capitalization refers to an inability to hear. While most Deaf people will also be deaf, there are many deaf individuals who do not consider themselves to be Deaf.

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